Sustainable Asphalt Rejuvenation using Waste Oils

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OULTINE

1. Road Pavements; European Policies; Sustainable Pavement Solutions

2. Introduction of the ongoing CoolAsphalt Project, which deals with the recycling of bituminous mixtures (HMA & WMA) with waste cooking oil as a rejuvenator

3. RAP – Reclaimed Asphalt Pavement

4. WMA – Warm Mix Asphalt

5. Project Results obtained so far

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ROAD PAVEMENTS

Roads are a vital part of modern life which most people take for granted.

- When we leave our home we need roads to go to work, to the shops, to school, to the cinema or to go on holiday.
- The goods and services we need are transported by road for at least part if not all of their journeys.
- In an emergency we rely on roads for the fire service, the ambulance and the police.

Road network is the Community most valuable asset.

More than 90% of European roads are surfaced with asphalt mixtures!

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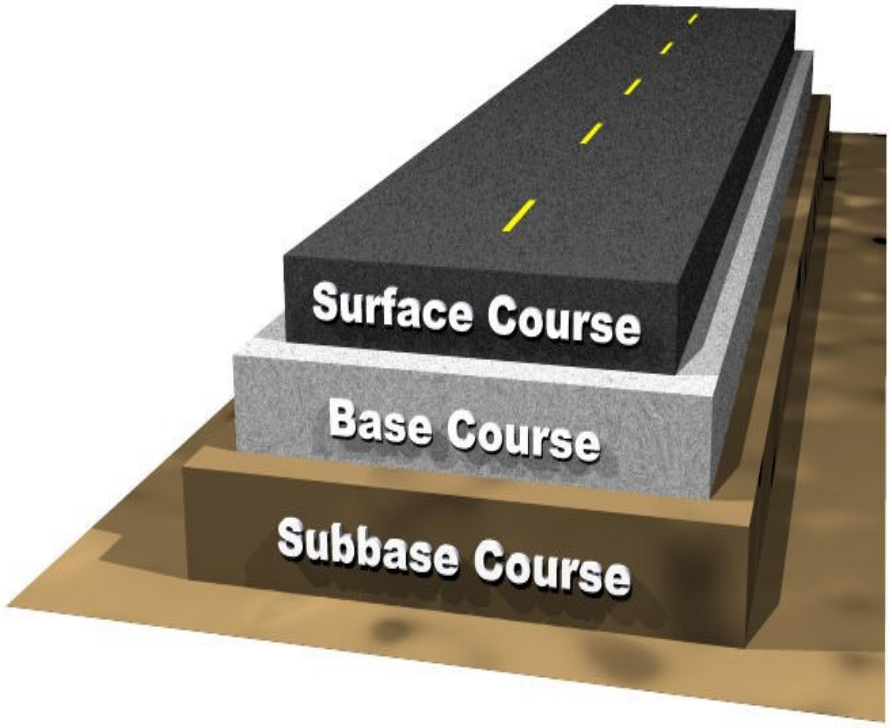
ROAD PAVEMENTS

Pavements are traditionally constructed using **hot-mix asphalt;**

The **average production temperature of hot-mix asphalt is between 150 and 180°C;**

It is a **mix of bitumen and virgin aggregates produced at high temperatures;**

This requires large amounts of natural resources and energy and releases a large quantity of waste.



Source: https://pavementinteractive.org

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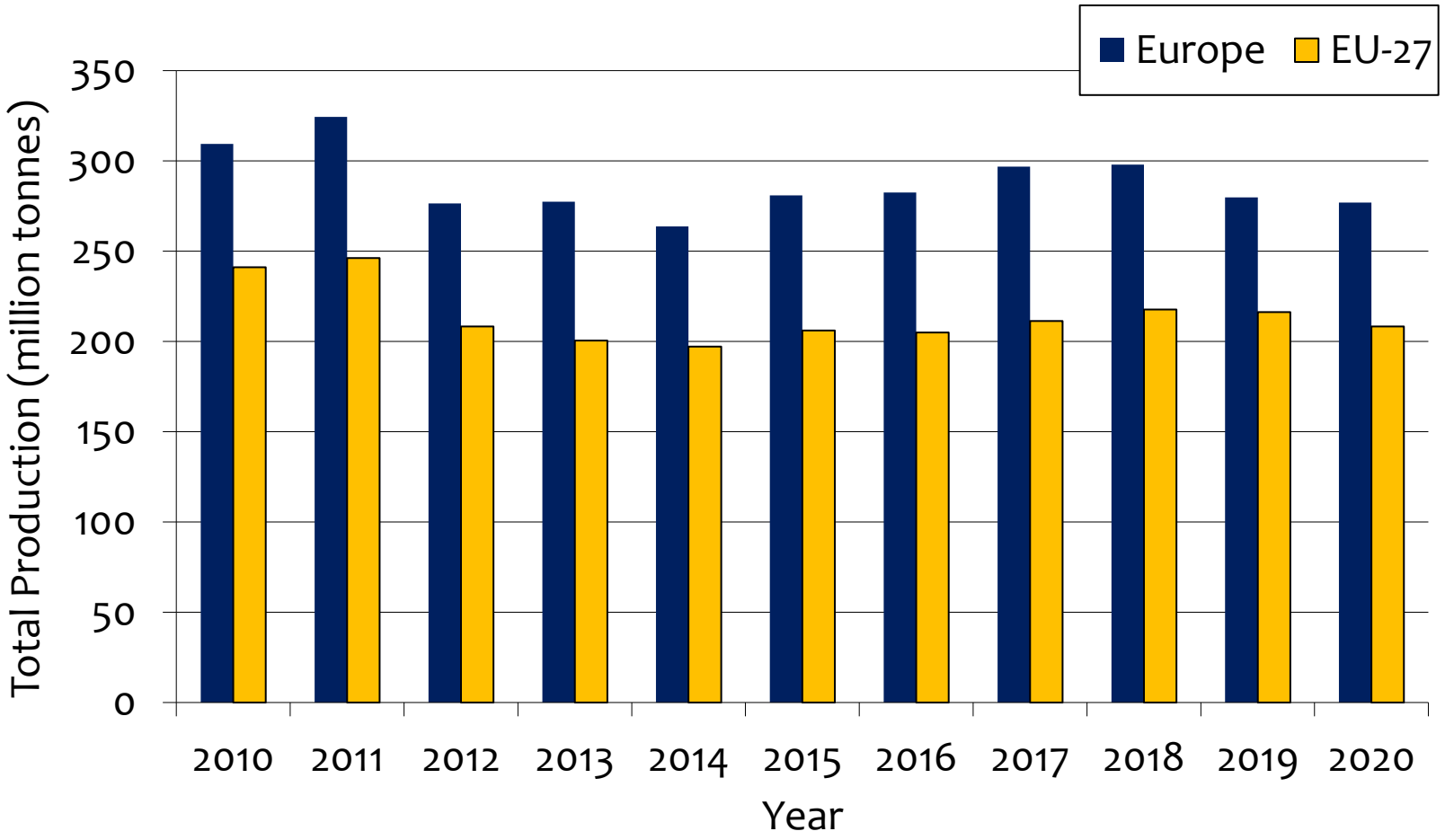
ROAD PAVEMENTS

https://eapa.org/asphalt-in-figures/



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EUROPEAN POLICY

- The European Green Deal - plans to make the EU's economy sustainable and achieve climate neutrality in 2050
- Environmental Product Declaration for Bituminous Materials
- The Roadmap to a Resource Efficient Europe
- …

The fewer products we discard, the less materials we extract, the better for our environment.

Source: https://ec.europa.eu/eurostat/web/circular-economy

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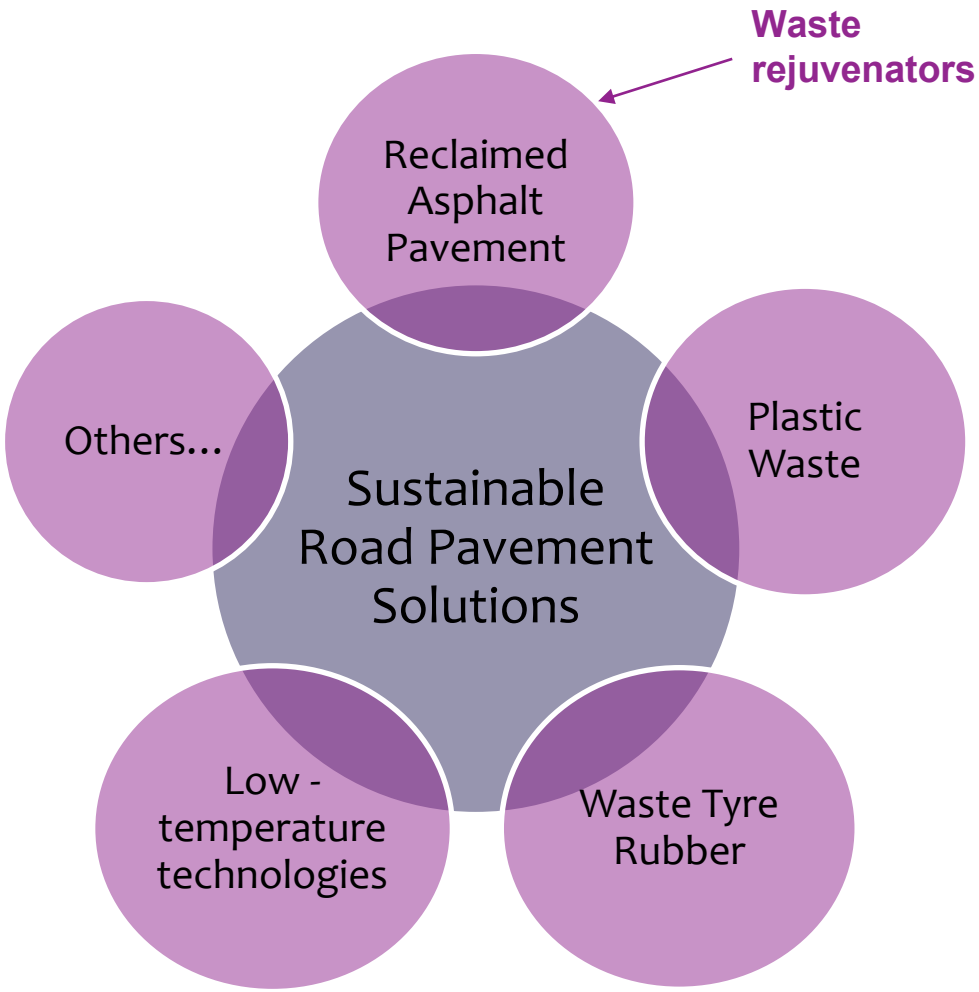
SUSTAINABLE ROAD PAVEMENT SOLUTIONS



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Ongoing Project - CoolAsphalt
(funded by European Union and Portugal 2020 Program)

CoolAsphalt - Full recycling of bituminous mixtures with waste cooking oil as a rejuvenator

30 months – 01/01/2021 – 30/06/2023

POCI-01-0247-FEDER-047037

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Ongoing Project - CoolAsphalt
(funded by European Union and Portugal 2020 Program)

- The project aims to **develop asphalt mixture products** based on **very high recycling RAP** and **waste cooking oil** as a rejuvenator **for low to medium-traffic roads** (in Portugal, those types of roads are about 90.000 km).
- **The project assesses hot- and warm-mix asphalt.**
- The **lab process must be compatible with the central plant-process**.
- Develop an **economic**, **sustainable** and **durable material** as well as the process to produce them.
- **Technology/material assessment and validation**.

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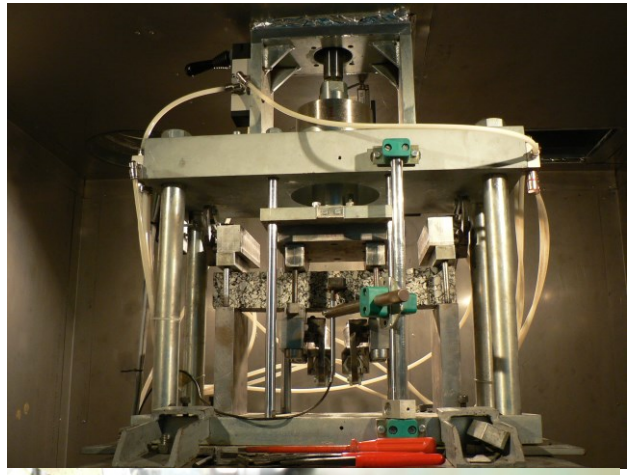

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Ongoing Project
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CoolAsphalt - Full recycling of bituminous mixtures with waste cooking oil as a rejuvenator

- **RAP – waste rejuvenators**
- **WMA**

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RAP - ASPHALT REJUVENATION

One of the characteristics of **RA binder is that it is usually much stiffer than typical virgin binders** used for asphalt mixtures due to the oxidative **ageing** of the RA binder that occurs during **asphalt mixture production** (high mixing and compaction temperatures) and the **service life** of the asphalt mixture.

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RAP - ASPHALT REJUVENATION

It is generally accepted that RA does not act in the mixture simply as **“Black Rock”**

… but it is also accepted that **full blending usually does not occur**.

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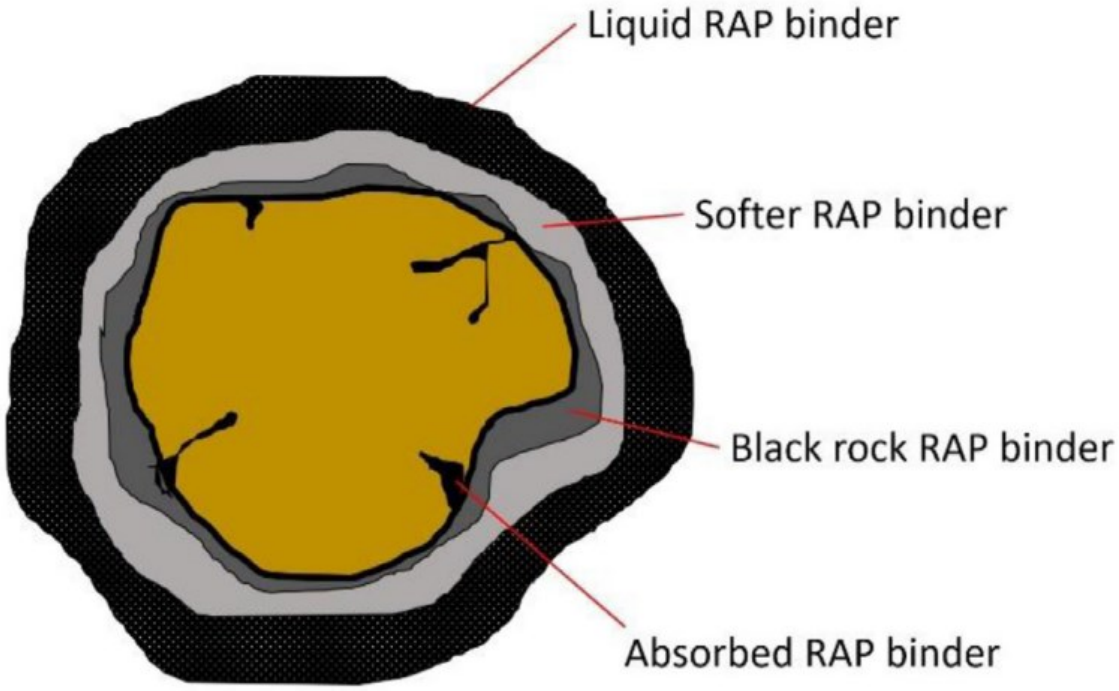
RAP - ASPHALT REJUVENATION

According to
Hettiarachchi et al. (2020)

**there are
four types of binders
on a RAP particle**



https://www.sciencedirect.com/science/article/pii/S0921344920302755

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RAP - ASPHALT REJUVENATION

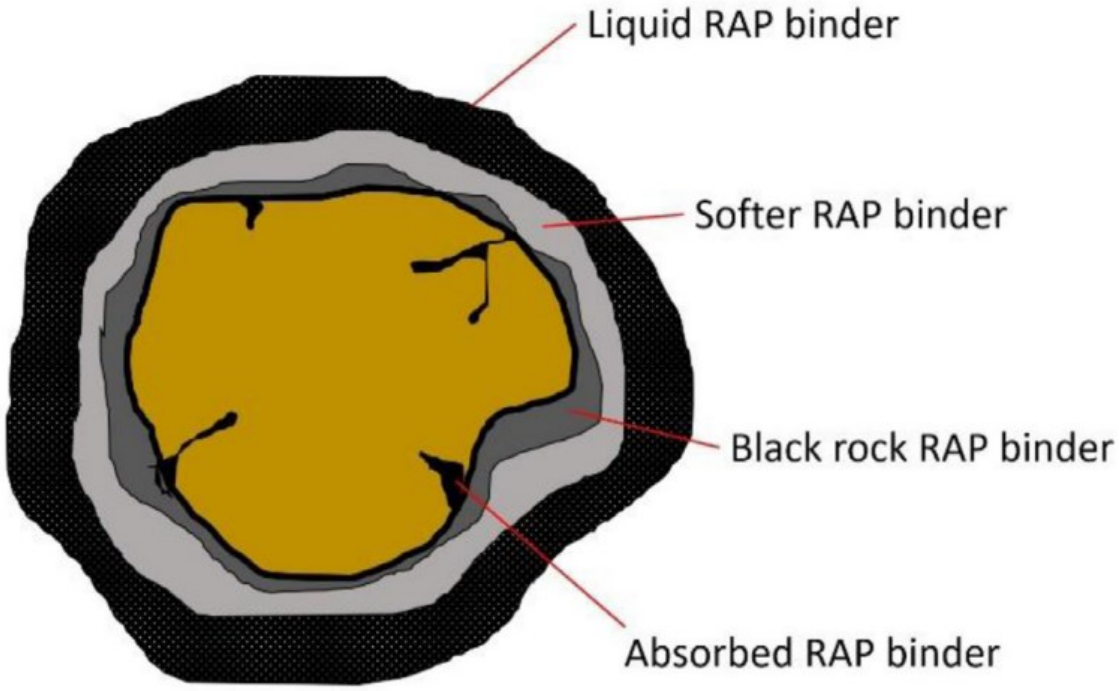
Liquid RAP binder

It is the component of binder that easily mobilize and blend with the virgin binder.

Softer RAP binder

This component softens under mixing temperatures. It becomes liquid RAP binder when enough time and temperature are provided.

Both liquid binder and softer binder together are called the available RAP binders



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RAP - ASPHALT REJUVENATION

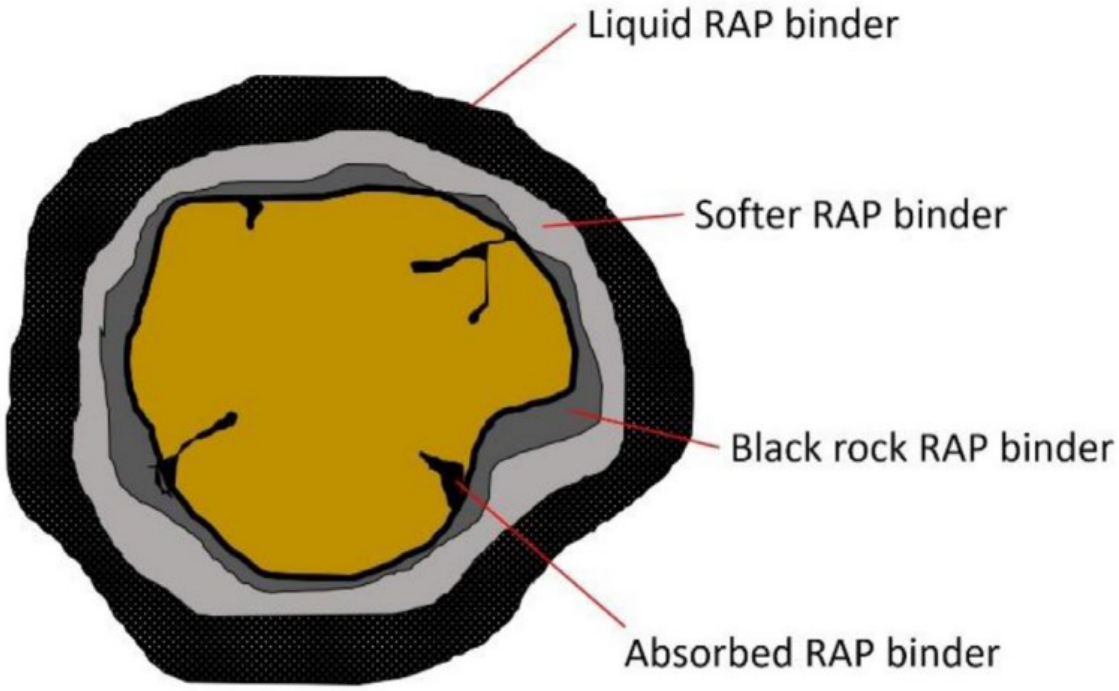
Black rock RAP binder

is the stiff and brittle binder component that has already become a part of the outer crust of the RAP aggregate.

Absorbed RAP binder

It binder absorbed into pore of aggregate.

Both black rock RAP binder and absorbed RAP binder together are called the unavailable RAP binder



https://www.sciencedirect.com/science/article/pii/S0921344920302755

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RAP - ASPHALT REJUVENATION

The amount of RA binder that is possibly activated during the manufacture of new asphalt mixtures containing RA has been described in the literature using various terms and definitions :

- the degree of blending (DOB)
- the degree of (re)activation
- mobilised binder
- mobilisation rate
- blending efficiency
- binder blending
- etc

Proportion of RA binder that is activated in the RA !

BLACK ROCK (0%)

https://www.tandfonline.com/doi/full/10.1080/14680629.2019.1663244

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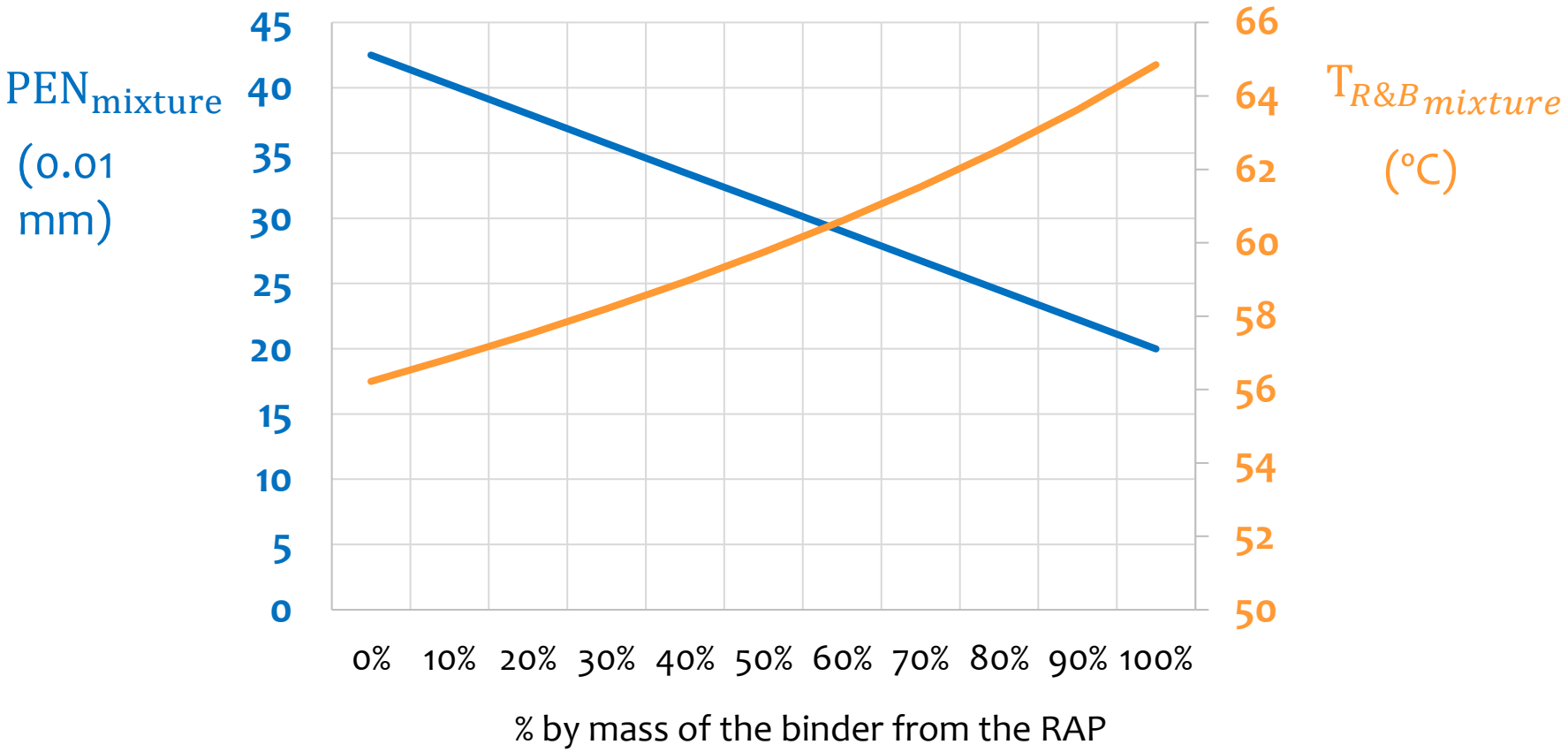
RAP - ASPHALT REJUVENATION



REJUVENATION

It is the process of reviving the properties by restoring the ratio of asphaltenes and maltenes in the aged binder with addition of a rejuvenator.

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RAP - ASPHALT REJUVENATION – WCO (Waste Cooking Oil)

Food industries and kitchens produces annually over 16.5 million tons of WCO

- disposed of along with municipal solid waste in landfills
  - could pollute the water and soil resources and subsequently disturb the ecosystem
- discharged into the sewage system
  - could reduce sewage pipes' diameter and block them, imposing economic and environmental costs

WCO CONSIDERED WASTE IS NOW A MAJOR SOURCE OF BIOFUEL

https://www.cleanindiajournal.com/extraction-of-biodiesel-from-waste-vegetable-oil/

https://www.sciencedirect.com/science/article/pii/S1364032122003197?via%3Dihub

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RAP - ASPHALT REJUVENATION – BHO (Bio Heating Oil)

Bio Heating Oil (BHO)

It is a residue of biodiesel production from waste cooking oil.

Appearance: Colour brownish, turbid, no visible impurities and water, in state of delivery solid.

Parameter	Method	Result	Unit
FAME/FFA content	ASG 2202-GC-FID	31	%
Monoglyceride content		<1	%
Sterols/Tocopherols		12	%
Content of FAME dimers		25	%
Diglyceride content		9	%
Sterol ester		7	%
Content of FAME trimers		-	%
Triglyceride content		13	%
Unknown high boilers		3	%
Pour point	DIN EN ISO 3016 :2017	+18	°C
Gross heat of combustion	ASTM D 240 :2019 mod.	38,81	MJ/kg
Net heat of combustion		36,40	MJ/kg
Ash content (925 °C)	ASTM D 482 :2019	0,023	% (m/m)
Density (40 °C)	DIN EN ISO 12185 :1997	926,1	kg/m³
Flash point	ASTM D 93 :2020	176,5	°C
Acid value	ASTM D 664 :2018	2,19	mg KOH/g
Sulfur content	ASTM D 5453 :2019	630	mg/kg
Nitrogen content	ASTM D 5762 :2018	725	mg/kg
Sediment content	DIN EN ISO 3735 :1999	0,25	% (m/m)
Calcium (Ca)	DIN EN ISO 11885 :2009	9	mg/kg
Potassium (K)		930	mg/kg
Magnesium (Mg)		5	mg/kg
Sodium (Na)		37	mg/kg
Phosphorous (P)		5	mg/kg
Sulfur (S)		570	mg/kg
Iodine content	DIN EN 15408 :2011	<0,001	% (m/m)

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RAP - PRODUCTION AND PAVEMENT TECHNOLOGY

The most commonly used principle of RAP incorporation into the asphalt production is by **superheating the virgin aggregates** so that when they come in contact they would dry and heat the RAP by conduction.

This prevents the exposure of RAP to direct flame.

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RAP - PRODUCTION AND PAVEMENT TECHNOLOGY

The superheating temperature depends on:

- the RAP content
- the RAP moisture
- the required discharge temperature

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RAP - PRODUCTION AND PAVEMENT TECHNOLOGY

Table 1. Superheating temperature of virgin aggregates for 50% RAP mixture (Virginia Department of Transportation, 1996).

Moisture content (%)	Superheat temperature (°C)			
	104°C discharge	115°C discharge	127°C discharge	138°C discharge
0	210	235	257	282
1	240	268	288	310
2	271	293	318	343
3	302	327	349	374
4	338	360	379	409
5	365	390	413	438

https://www.tandfonline.com/doi/abs/10.1080/10298436.2014.893331

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RAP -Re-use and Recycling of Reclaimed Asphalt in 2020 (EAPA)

Country	Total amount of site-won asphalt generated in 2020 in tonnes	Amount of reclaimed asphalt available to be used by the asphalt industry in 2020 in tonnes	% of available reclaimed asphalt used in						Applied area in m2 of hot reuse of existing asphalt pavement material in-situ / on the road (Remixing, Repaving, Reshaping, Road Train etc.)	The amount of "only" reheated (reused) asphalt material in-situ / on the road (Remixing, Repaving, Reshaping , Road Train etc.) in metric tonnes
			Hot and Warm Mix Asphalt Production	Half Warm Mix Asphalt Production	On-Site Cold Recycling**	Plant Cold Recycling**	Unbound Road Layers	Other Civil Engineering Applications	Put to Landfill /Other Applications/ Unknown	
Austria	1,800,000	1,260,000	70	30						no data	no data
Belgium	no data	1,981,500	47	no data	no data	no data	no data	no data	no data	no data	no data
Croatia	280,000	240,000	33	0	0	2	no data	no data	no data	no data	no data
Czech Republic	2,700,000	2,500,000	15	no data	25	no data	25	7	28	no data	no data
Denmark	1,410,000	1,160,000	85	no data	no data	no data	15	no data	no data	no data	no data
Finland	1,600,000	no data	100	0	0	0	0	0	0	12,000,000	no data
France	8.056.000	6.042.000	76	10	no data	no data	no data	no data	no data	1.171.000***	0
Germany	13,800,000	11,600,000	84	0	0	0	16	0	0	no data	no data
Great Britain	5,525,673	4,973,106	37	no data	no data	no data	63		no data	no data	no data
Hungary	200,000	140,000	95	0	0	3	2	0	0	no data	no data
Ireland	500,000	220,000	100	0	0	0	0	0	0	no data	no data
Italy	no data	9.500.000*	25*	75*						no data	no data
Norway	1,300,000	840,000	35	0	0	0	65	0	0	no data	no data
Romania	10,425	no data	0	0	100	0	0	0	0	279,910	120
Slovakia	no data	135,846	53	0	30	0	17	0	0	no data	no data
Slovenia	no data	170,000	29	0	10	1	25	10	25	no data	no data
Spain	2,400,000	1,900,000	72.7	0.2	0.2	0	24	3	0	no data	no data
Turkey	no data	2,143,354	2	0	0	0	98	0	0	no data	no data
USA	87,000,000	85,000,000	93	0	0	0.4	6.2	0.3	0	no data	no data

* Data not available. Estimated based on historic data

** Cold recycling includes stabilisation with bitumen emulsion, foamed bitumen and/or cement.

*** Only remix and repave with bitumen emulsion

Country	Total amount of site-won asphalt generated in 2020 in tonnes	Amount of reclaimed asphalt available to be used by the asphalt industry in 2020 in tonnes	phalt used in				
			Hot and Warm Mix Asphalt Production	I /	Unbound Road Layers	Other Civil Engineering Applications	F / (U
Austria	1,800,000	1,260,000	70	30			
Belgium	no data	1,981,500	47		no data	no data	
Croatia	280,000	240,000	33		no data	no data	
Czech Republic	2,700,000	2,500,000	15		25	7	
Denmark	1,410,000	1,160,000	85		15	no data	
Finland	1,600,000	no data	100		0	0	
France	8.056.000	6.042.000	76		no data	no data	
Germany	13,800,000	11,600,000	84		16	0	
Great Britain	5,525,673	4,973,106	37		63		
Hungary	200,000	140,000	95		2	0	
Ireland	500,000	220,000	100		0	0	
Italy	no data	9.500.000*	25*	75*			
Norway	1,300,000	840,000	35		65	0	
Romania	10,425	no data	0		0	0	
Slovakia	no data	135,846	53		17	0	
Slovenia	no data	170,000	29		25	10	
Spain	2,400,000	1,900,000	72.7		24	3	
Turkey	no data	2,143,354	2		98	0	
USA	87,000,000	85,000,000	93		6.2	0.3	

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RAP - ASPHALT REJUVENATION

It is crucial to use RAP in the top layers of the road pavement instead of in the unbound layers since **a less expensive RAP binder can replace a portion of the more expensive virgin binder**.

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Ongoing Project
(funded by European Union and Portugal 2020 Program)

CoolAsphalt - Full recycling of bituminous mixtures with waste cooking oil as a rejuvenator

- **RAP – waste rejuvenators**
- **WMA**

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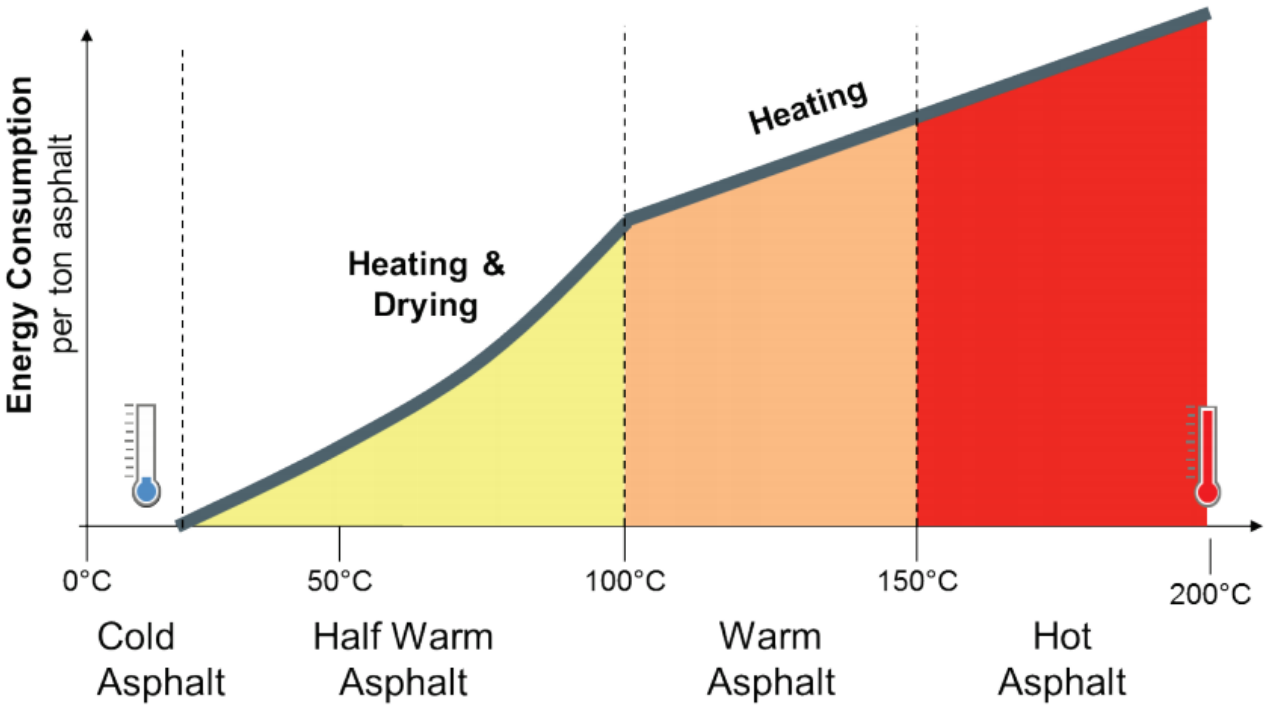
WARM MIX ASPHALT



Cold Asphalt: produced with unheated aggregate and bitumen emulsion or foamed bitumen.

Half Warm Asphalt: produced between approximately 70 °C and roughly 100 °C.

Warm Mix Asphalt: produced and mixed at temperatures roughly between 100 and 150 °C.

Hot Mix Asphalt: produced and mixed at temperatures roughly between 150 and 190 °C The production temperatures of HMA depend on the bitumen used.

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WARM MIX ASPHALT

Warm mix asphalt (WMA) from different warm mix technologies (foaming technology, organic additives, chemical agents) **can be prepared and compacted at reduced temperatures in comparison to hot mix asphalt** (HMA).

They offer unique environmental and economic benefits by **reducing the energy consumption**, fuel cost, and hauling distance.

WMA technologies **lessen harmful emissions and hazardous fumes from asphalt production plants**, thereby improving the working condition for plant operators and workers.

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WARM MIX ASPHALT

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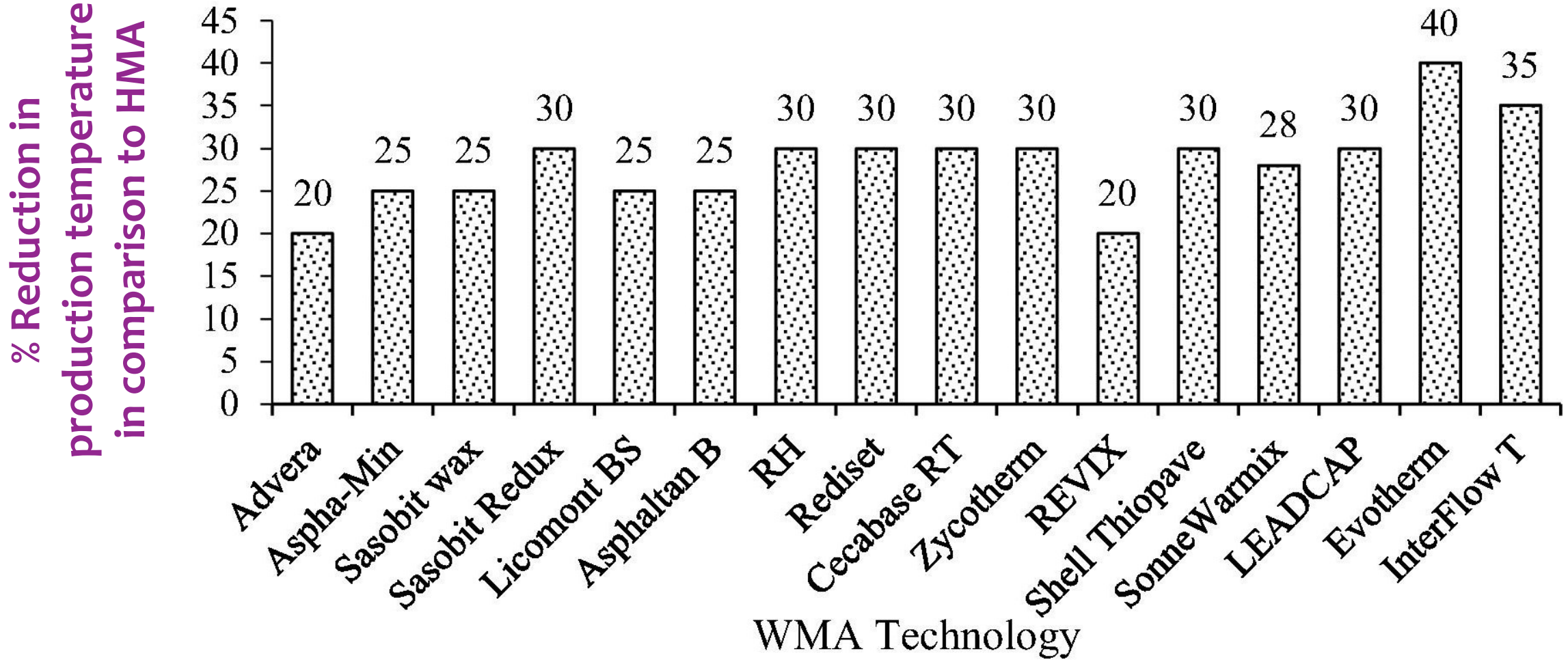
WARM MIX ASPHALT



A comprehensive review of warm mix asphalt mixtures-laboratory to field – ScienceDirect

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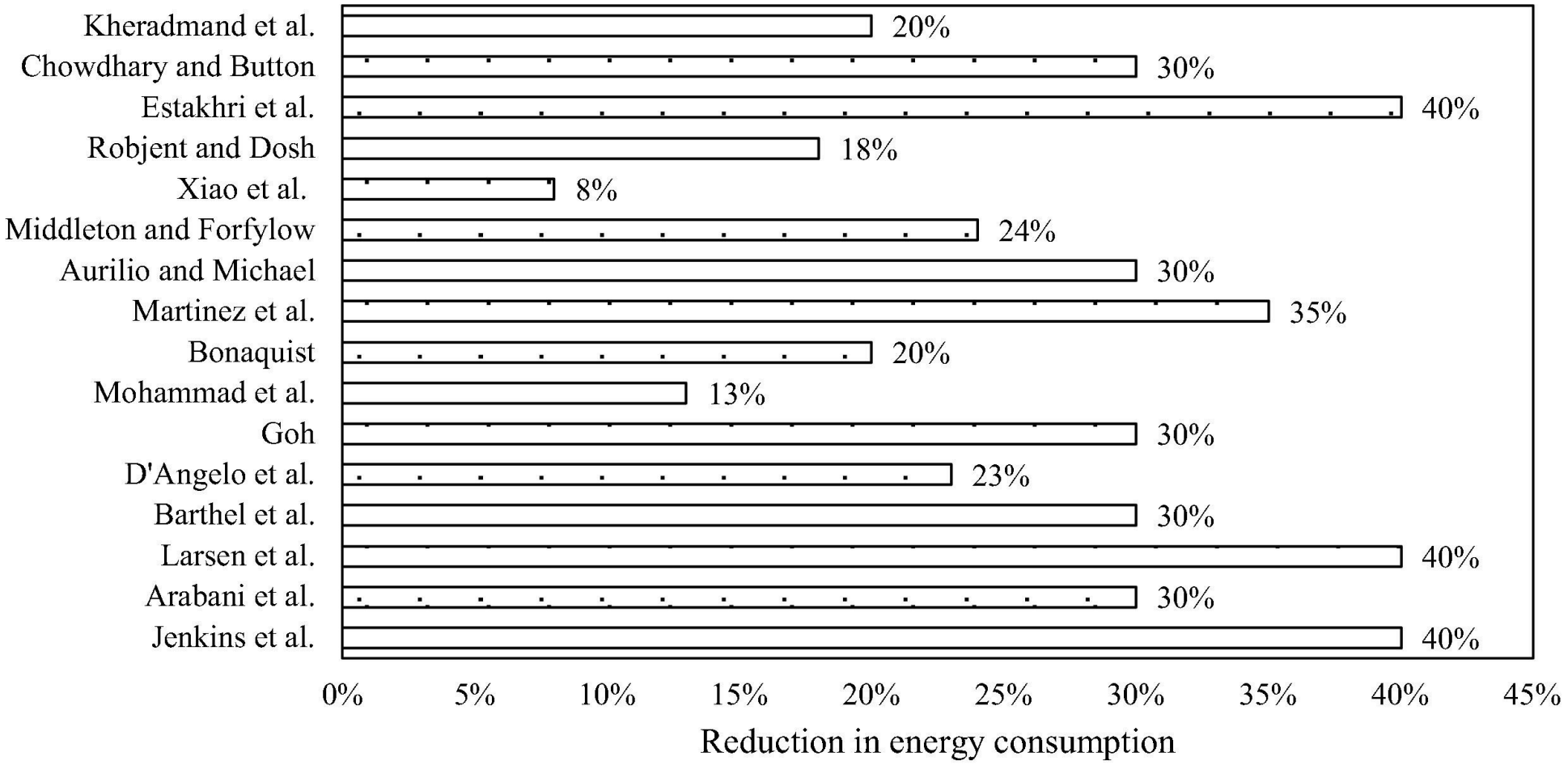
WARM MIX ASPHALT

The significant economic benefit of WMA is associated with the reduction in energy consumption during the production of WMA.



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WARM MIX ASPHALT

Warm Mix Asphalt (WMA) is the generic term for a variety of technologies that enable Hot Mix Asphalt (HMA) pavement material to be produced, placed and compacted at lower temperatures without compromising quality or performance. It is a proven technology that can:

- Reduce paving costs
- Extend the paving season
- Improve asphalt compaction
- Allow asphalt mix to be hauled longer distances
- Improve working conditions by reducing exposure to fuel emissions, fumes, and odors
- Reduce greenhouse gas emissions
- Allow the increase of RAP content

WARM MIX ASPHALT (WMA) PRODUCTION IN THE PERIOD 2013 - 2020 (IN MILLION TONNES)

Country	2013	2014	2015	2016	2017	2018	2019	2020
Austria	0.000	0.000	0.000	0.000	no data	no data	no data	no data
Belgium	no data	no data	<0,05	no data	<0,050	0.100	0.200	0.300
Croatia	0.000	0.040	0.060	0.060	no data	no data	no data	0.075
Czech Rep	0.030	0.001	0.020	0.007	0.070	0.080	0.001	0.001
Denmark	0.120	0.200	0.200	0.250	0.340	0.330	0.320	0.320
Estonia	no data	no data	0.008	no data	no data	no data	no data	no data
Finland	0.000	0.120	0.240	0.310	0.430	0.310	0.200	0.200
France	3.550	4.023	4.552	4.324	3.824	3.728	4.305	4,058
Great Britain[1]	<1,000	<1,000	no data	<0,300	<1,000	<1,000	>1,000	1.000
Hungary	0.020	0.038	0.070	0.208	0.210	0.000	0.180	0.350
Luxemburg	0.000	0.007	0.007	0,007*	no data	no data	no data	no data
Netherlands	0.060	0.133	0.100	0,100*	0.060	no data	no data	no data
Norway	0.380	0.540	0.592	0.502	0.869	1.339	1.740	1.851
Portugal	no data	no data	no data	no data	no data	no data	0.100	0.500
Slovakia	no data	no data	0.014	0.035	0.050	0.030	0.035	0.004
Slovenia	0.000	0.000	0.000	0.000	0.050	0.002	0.000	0.040
Spain	0.086	0.140	0.140	0.060	0.200	0.180	0.380	0.500
Sweden	0.500	0.700	0.700	0,700*	no data	no data	no data	no data
Switzerland	0.870	0.388	no data	no data	no data	no data	0.500	no data
Turkey	no data	no data	0.080	0.151	0.077	0.000	0.000	0.000
USA[2]	69.000	103.000	109.000	106.000	133.000	143.000	150.000	169.000
Ontario-Canada	no data	0.750	0.900	0.750	no data	no data	no data	no data
South Africa	0.150	0.150	0.200	0.200	no data	no data	no data	no data

EAPA

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CoolAsphalt - Full recycling of bituminous mixtures with waste cooking oil as a rejuvenator

- RAP
  - 80%
  - 60%
- HMA and WMA
- Rejuvenators
  - WCO
  - BHO

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RAP

JJR construções, sa

Age: about 14 years

Coarse RAP: granite

Fine RAP: granite and limestone

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RAP

Homogeneity of RAP

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RAP

AC 14 surf 35/50

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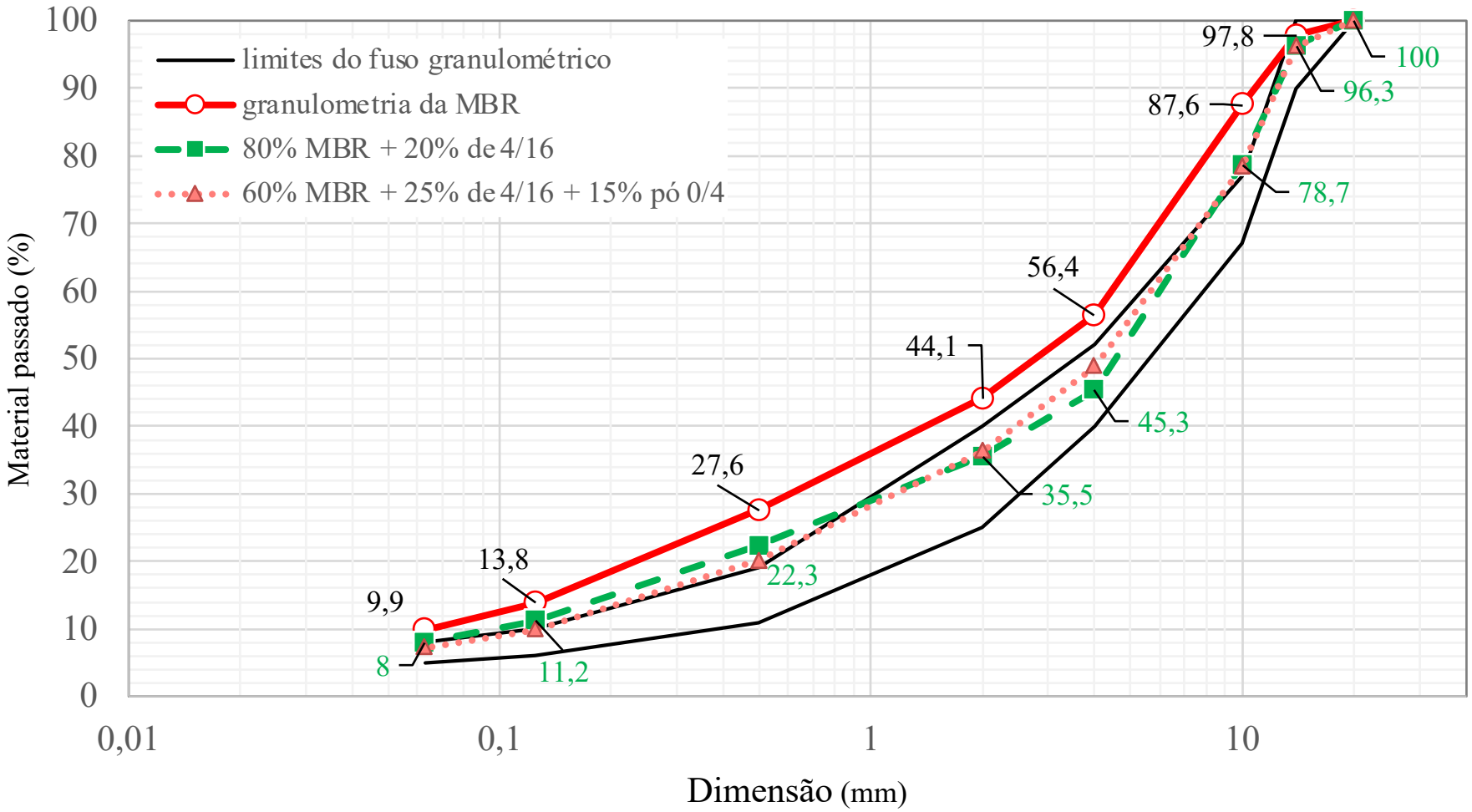

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RAP

EN 12697-39
Bituminous mixtures
Test methods for hot mix asphalt
Part 39: Binder content by ignition

The test method determines the binder content of bituminous mixtures by ignition of the mixture in a furnace.

Binder Content: 4.5%

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(funded by European Union and Portugal 2020 Program)

EN 13108-1 - Calculations of the penetration or the softening point of the binder of a mixture when reclaimed asphalt is used

Note: these calculations shall only be applied when paving grade bitumen has been used in the reclaimed asphalt and will be used as added binder.

$$\log(PEN_{mixture}) = \frac{\%_{new} \times \log(PEN_{new}) + \%_{RAP} \times \log(PEN_{RAP})}{\%_{new} + \%_{RAP}}$$

$$T_{R\&B\,mixture} = 99{,}13 - 26{,}35 \times \log(PEN_{mixture})$$

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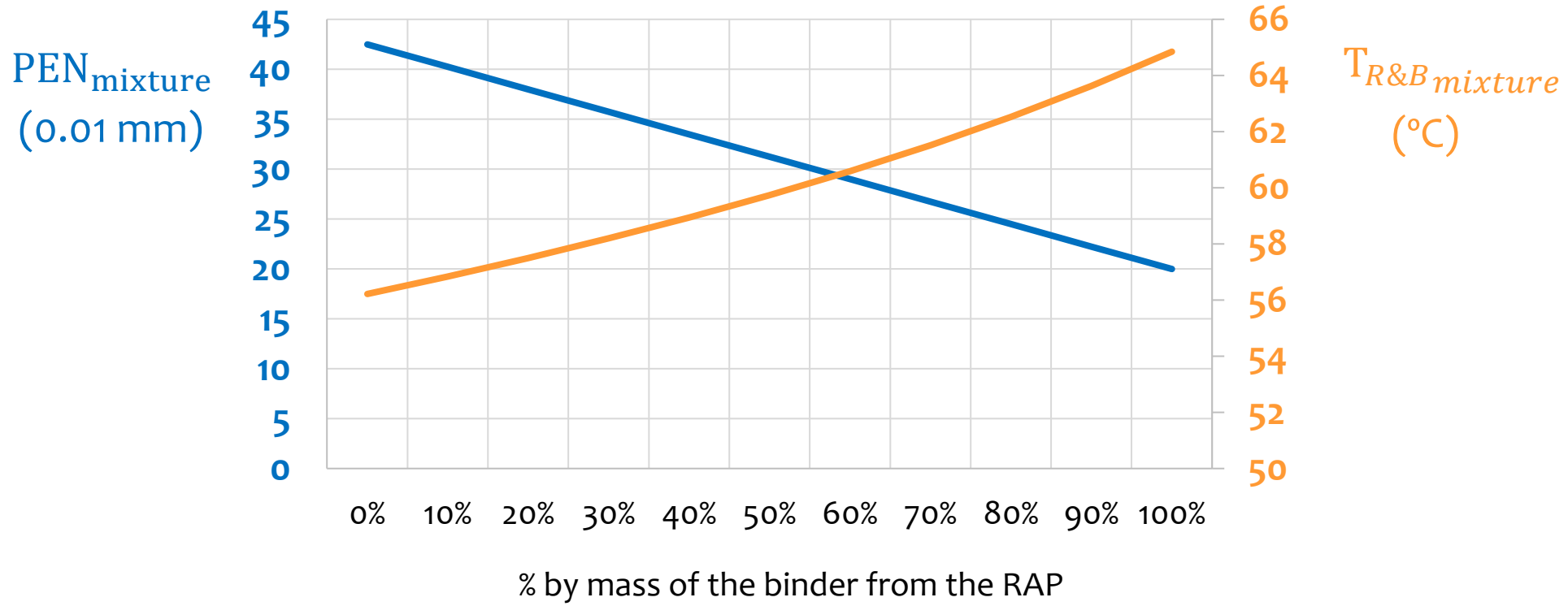

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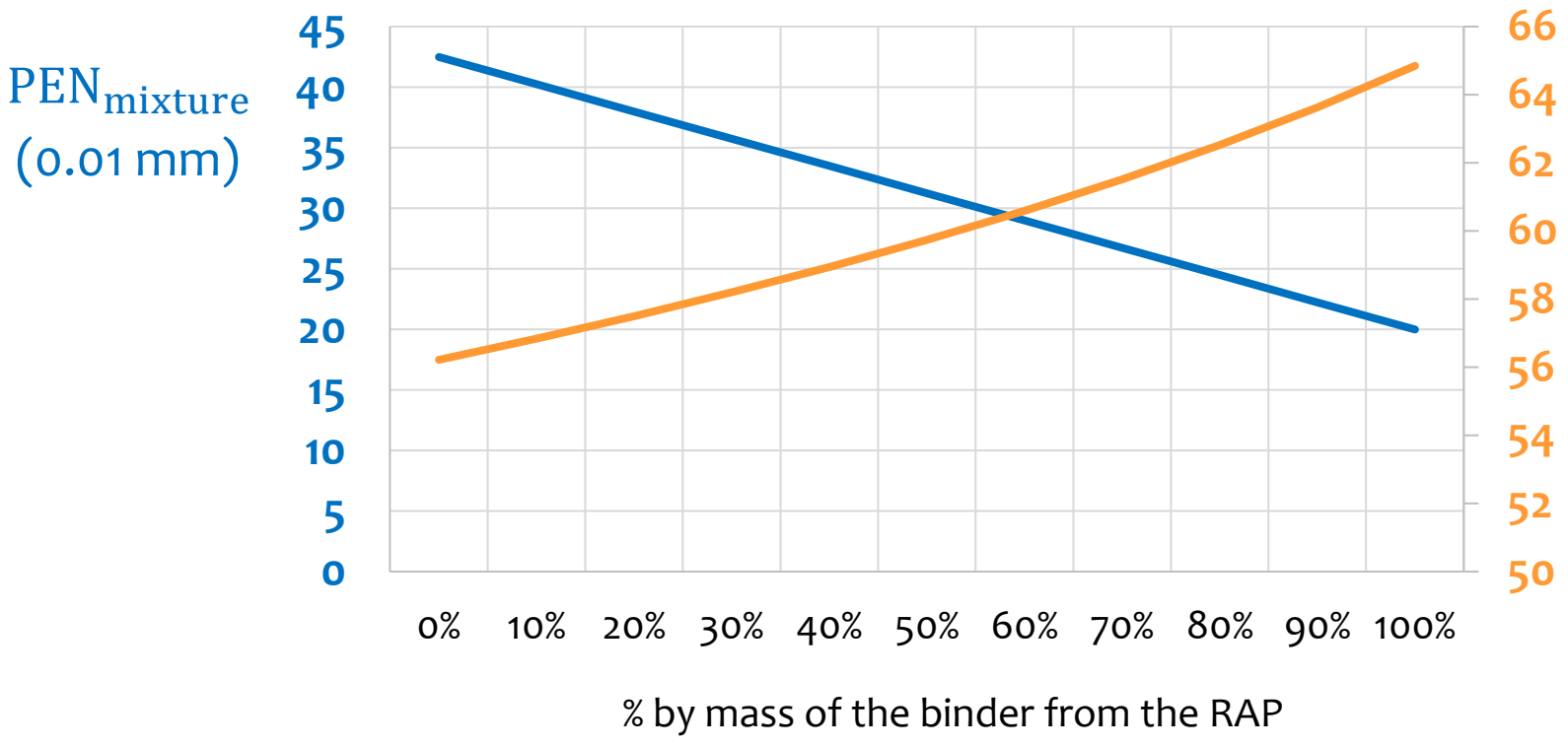
EN 13108-1 - Calculations of the penetration or the softening point of the binder of a mixture when reclaimed asphalt is used



10% WCO

10% BHO

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BITUMEN CONTENT (60 AND 80% RAP)

$$t_b = K \times \frac{2{,}65}{\rho_a} \times \sqrt[5]{S_e}$$

80% RAP - 0.6%
60% RAP – 1.0%

$$S_e = \frac{1}{100}(0{,}25\,G + 2{,}3\,S + 12\,s + 135\,f)$$

tb – Bitumen content (relation between bitumen mass and aggregates mass)

K - Richness modulus (about 3.2 for a AC14)

ρa – Mix aggregates density (g/cm³)

Se – Specific surface of aggregates mix (m²/kg)

G, S, s and f - ponderal percentages of aggregates
- G - higher than 6.3 mm
- S – between 6.3 and 0.315 mm
- s – between 0.315 and 0.08 mm
- f – lower than 0.08 mm

Delorme et al., 2007] J.L. Delorme, C. La Roche, L. Wendling (2007). Manuel LPC d'aide àla formulation des enrobés, Groupe de travail RST Formulation des enrobés, Paris,Laboratoire des Ponts et Chaussées.

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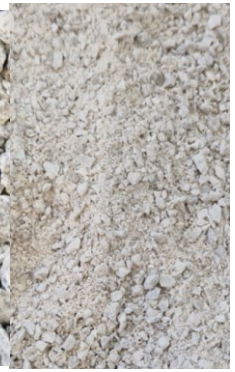
	Virgin Aggregates					
	RAP	4/16	0/4	Virgin Bitumen	WCO or BHO	Sasobit
					 	
HMA	80% 60%	20% 25%	- 15%	0.6% 1.0%	10%	-
WMA	80% 60%	20% 25%	- 15%	0.6% 1.0%	10%	1.5%

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Water Sensitivity

EN 12697-12 - Bituminous mixtures - Test methods for hot mix asphalt

Part 12: Determination of the water sensitivity of bituminous specimens

Water sensitivity is expressed as the ITSR value

ratio of the indirect tensile strength of wet (water conditioned) specimens to that of dry specimens

1. A set of cylindrical test specimens is divided into two equally sized subsets and conditioned.
2. One subset is maintained dry at room temperature while the other subset is saturated and stored in water at elevated conditioning temperature.
3. After conditioning, the indirect tensile strength of each of the two subsets is determined in accordance with EN 12697-23 at the specified test temperature.
4. The ratio of the indirect tensile strength of the water conditioned subset compared to that of the dry subset is determined and expressed in percent.

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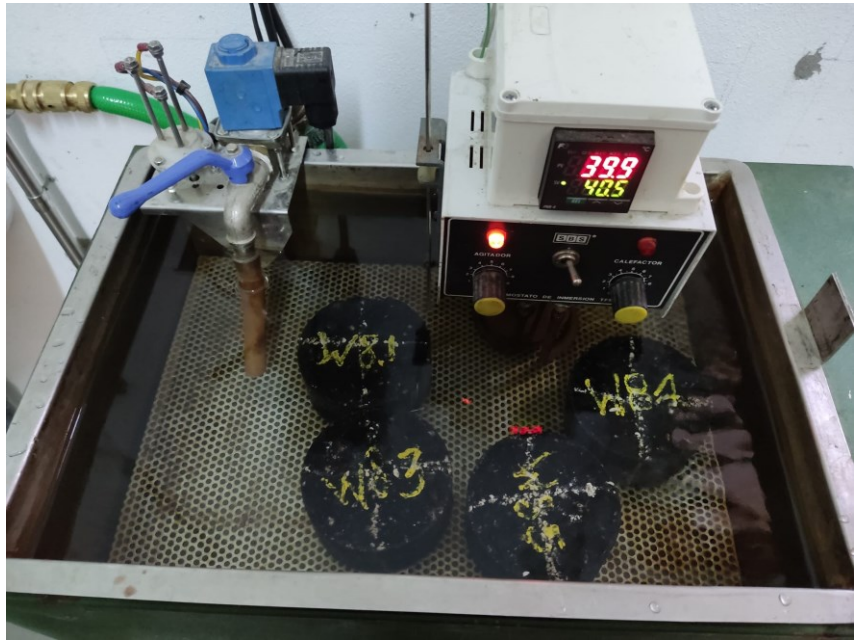
Water Sensitivity

water conditioned subset

- Place the specimens on the perforated shelf in the vacuum container;
- Apply vaccum
- Measure and calculate the volume of the specimens
- Reject any specimen which has increased more than 2 % in volume.



Place the wet subset of specimens in a water bath at 40°C for a period of 72 h

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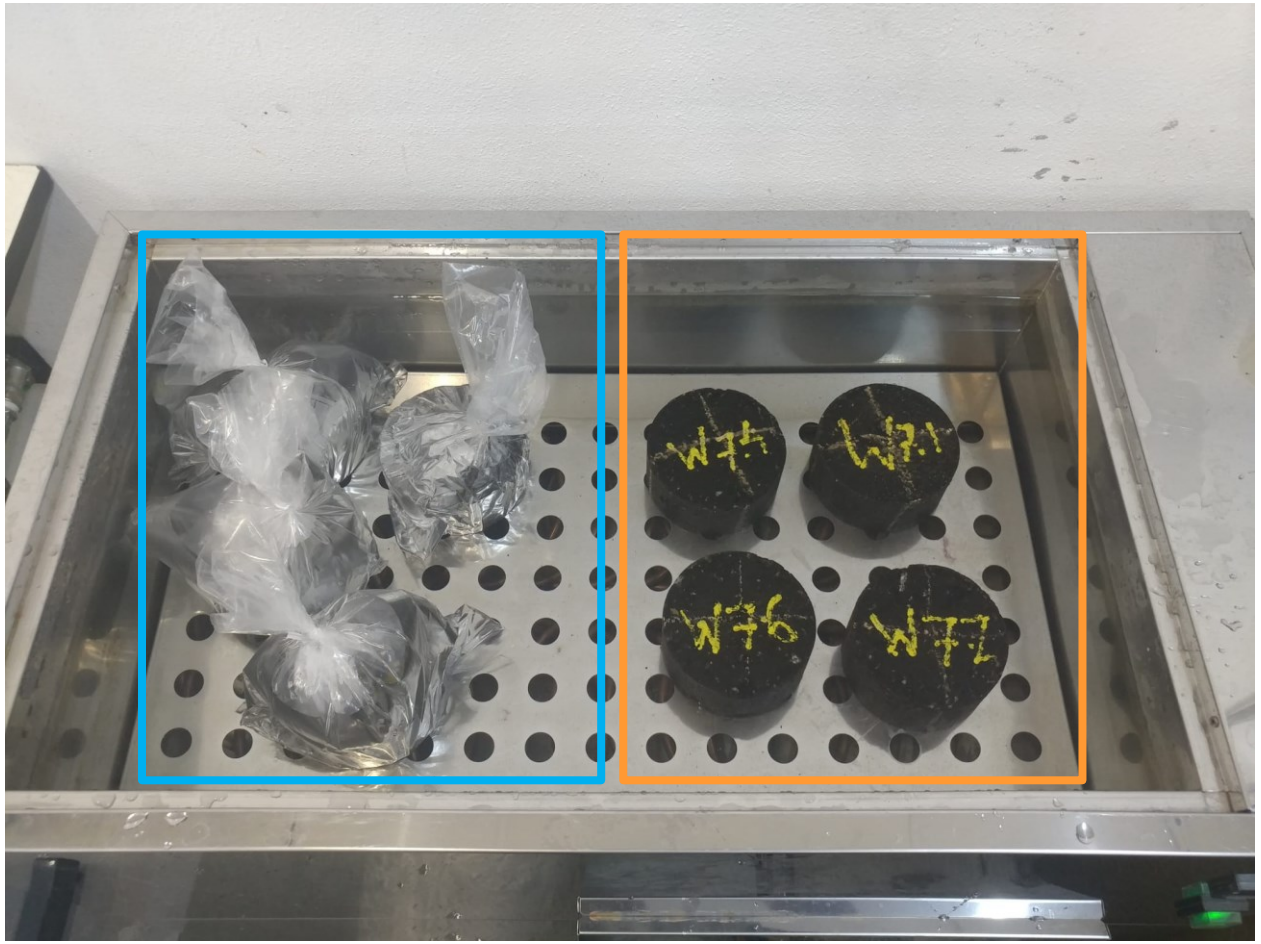
Water Sensitivity

Bring the test specimens (2 hours) to the test temperature – **15°C**

Dry specimens protected from the water by a plastic bag

Wet specimens



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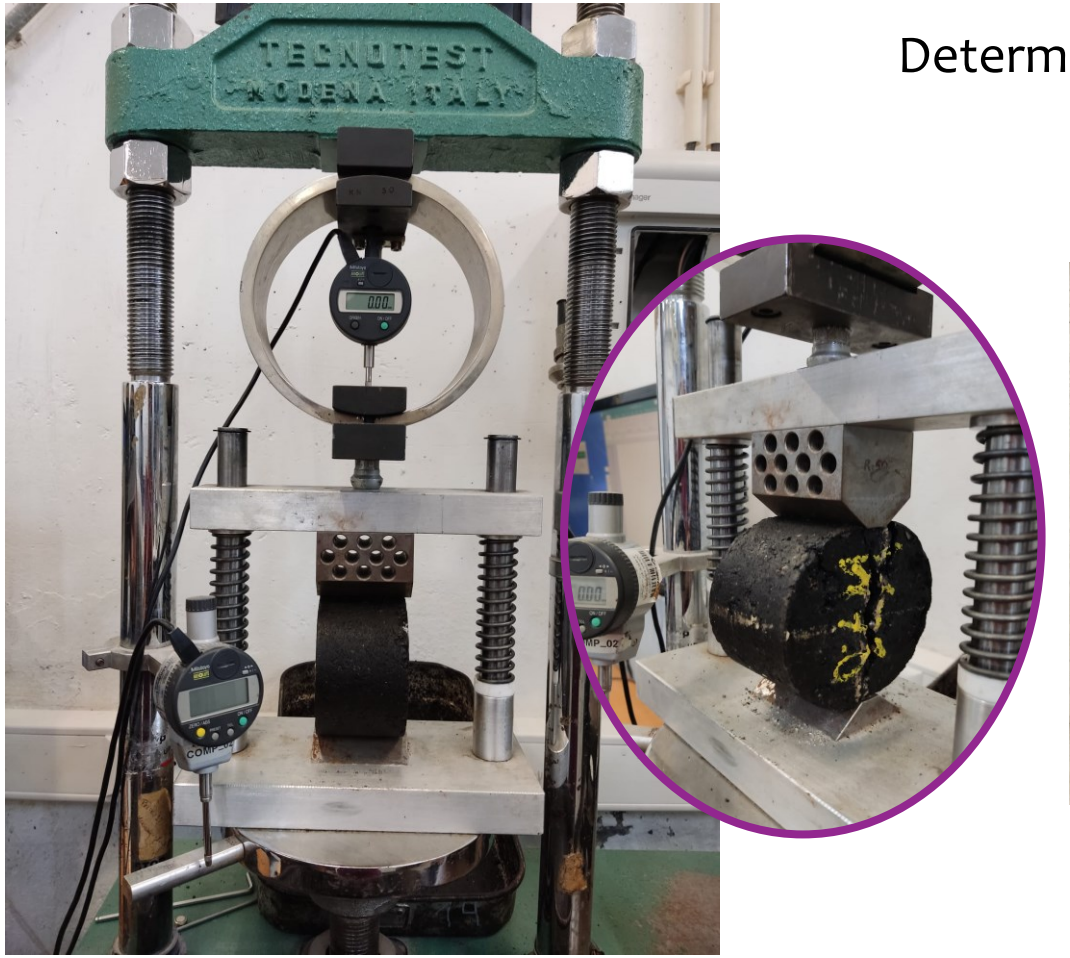
Water Sensitivity



Determine the indirect tensile strength on the test specimens in accordance with the procedure in EN 12697-23.

$$ITSR = 100 \times \frac{ITS_w}{ITS_d}$$

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Water Sensitivity

- HMA
  - WCO & 80% RAP
  - WCO & 60% RAP
  - BHO & 60% RAP
- WMA
  - WCO & 80% RAP
  - BHO & 80% RAP

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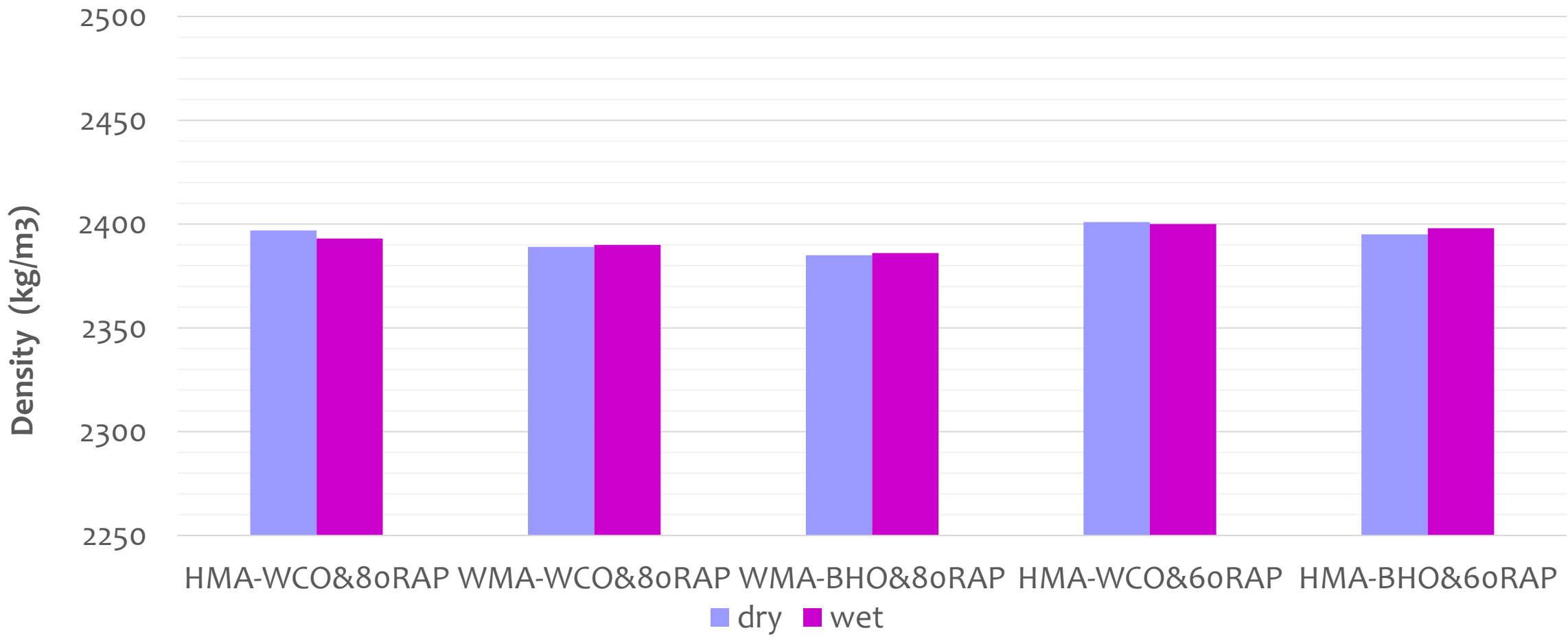
Water Sensitivity



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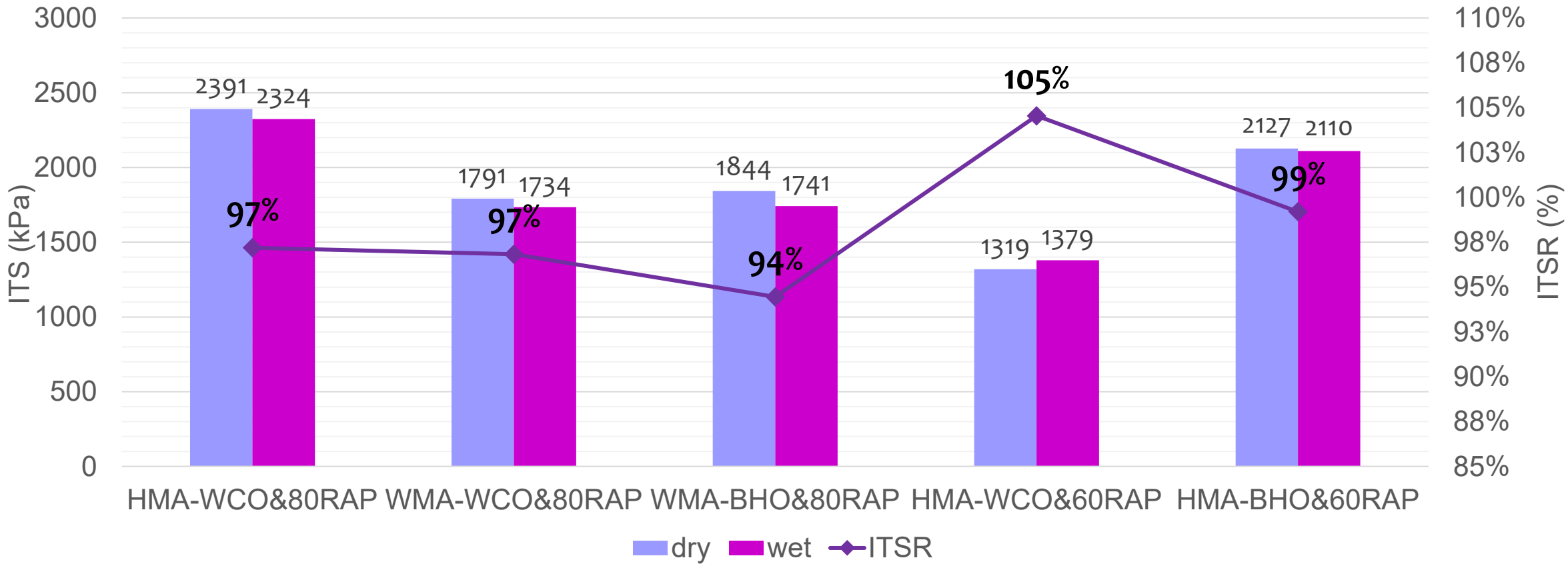
Water Sensitivity



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Permanent Deformation

Preparation of the test specimens (slabs)

2 per mix

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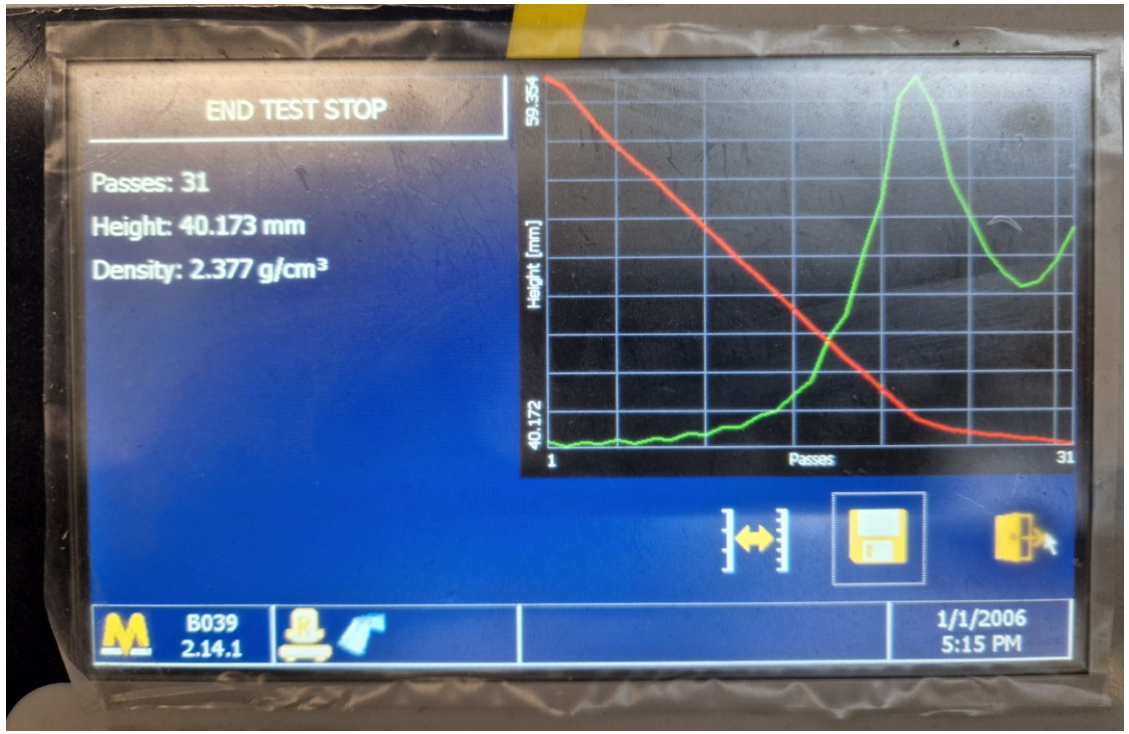
Permanent Deformation

EN 12697-33 - Bituminous mixtures - Test methods for hot mix asphalt

Part 33: Specimen prepared by roller compactor



[DATA]
Test: HMA-2
Test type: Roller compactor test
Test date: 6/8/2022
Test time: 12:04:09 PM

Vibrator: Disabled
Mould: D2[305x305x100]
Roller: D[305x305]
Cycle mode: Deformation
Weight: 8.869 kg
Stop mode: Passes+Height
Expected height: 40.000 mm

[RESULTS]
END TEST STOP
Passes: 31
Height: 40.151 mm
Density: 2.375 g/cm³

Passes	Height [mm]	Load [kN]	Roll temperature [°C]	Cart temperature [°C]
1	56.132	0.123	179.4	90.4
2	55.667	-0.087	179.5	90.4
3	54.838	0.046	179.5	90.5
4	53.928	-0.022	179.6	90.5
5	53.198	0.109	179.6	90.5
6	52.494	0.014	179.6	90.5
7	51.851	0.175	179.8	90.5
8	51.084	0.102	179.8	90.5
9	50.402	0.337	179.9	90.6
10	49.591	0.285	180	90.6
11	48.94	0.575	180.1	90.6
12	48.194	0.481	180.1	90.6
13	47.62	1.02	180.1	90.6
14	46.739	0.882	180.2	90.6
15	46.124	1.965	180.3	90.6
16	45.284	1.746	180.3	90.6
17	44.728	3.218	180.4	90.6
18	43.919	3.386	180.4	90.6
19	43.373	5.344	180.4	90.6
20	42.567	6.18	180.6	90.6
21	41.941	8.712	180.7	90.6
22	41.295	8.801	180.7	90.6
23	41.026	8.251	180.7	90.6
24	40.775	6.297	180.8	90.6
25	40.717	5.923	180.8	90.6
26	40.546	4.718	180.8	90.6
27	40.547	4.691	180.9	90.6
28	40.375	3.964	180.9	90.6
29	40.343	4.223	180.9	90.6
30	40.205	4.083	181.1	90.7
31	40.151	4.879	181.1	90.7

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Permanent Deformation

EN 12697-22 - Bituminous mixtures - Test methods for hot mix asphalt

Part 22: Wheel tracking

The susceptibility of bituminous materials to deform is assessed by the rut formed by repeated passes of a loaded wheel at constant temperature.

Continue tracking until 10 000 load cycles are applied or until a rut depth of 20 mm is reached whichever is the shorter.

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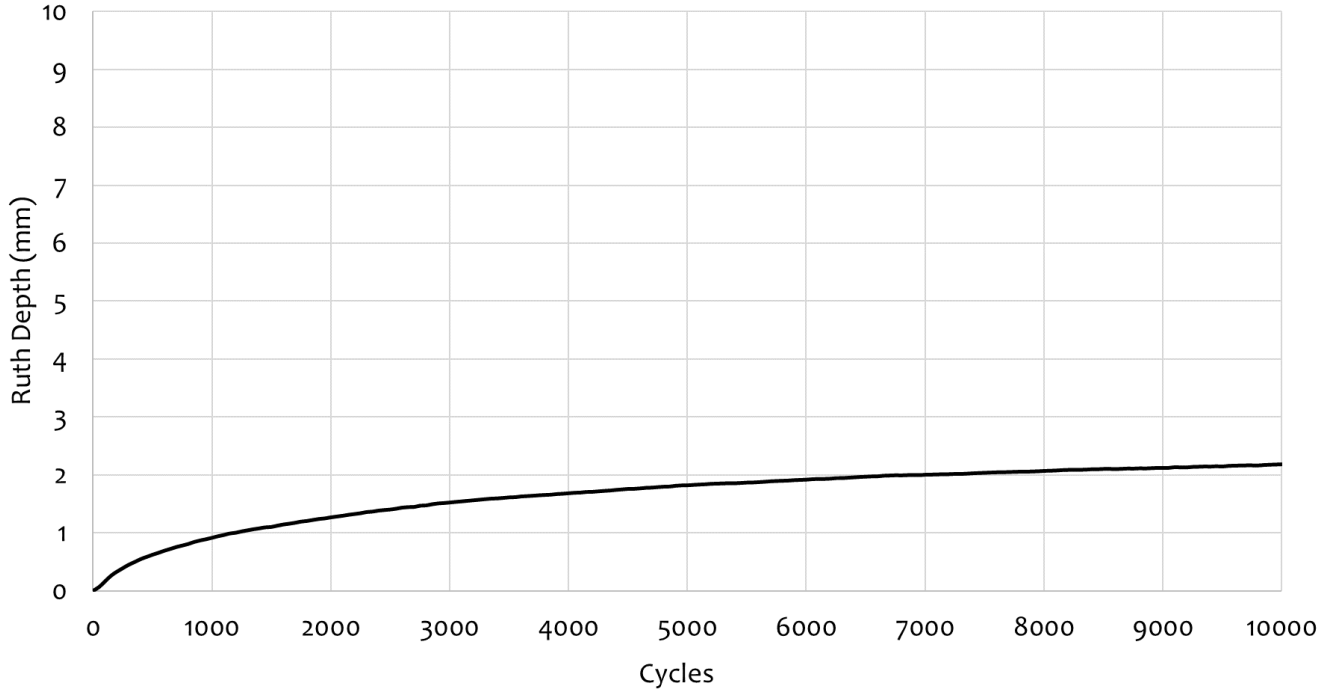
Permanent Deformation

EN 12697-22 - Bituminous mixtures - Test methods for hot mix asphalt

Part 22: Wheel tracking



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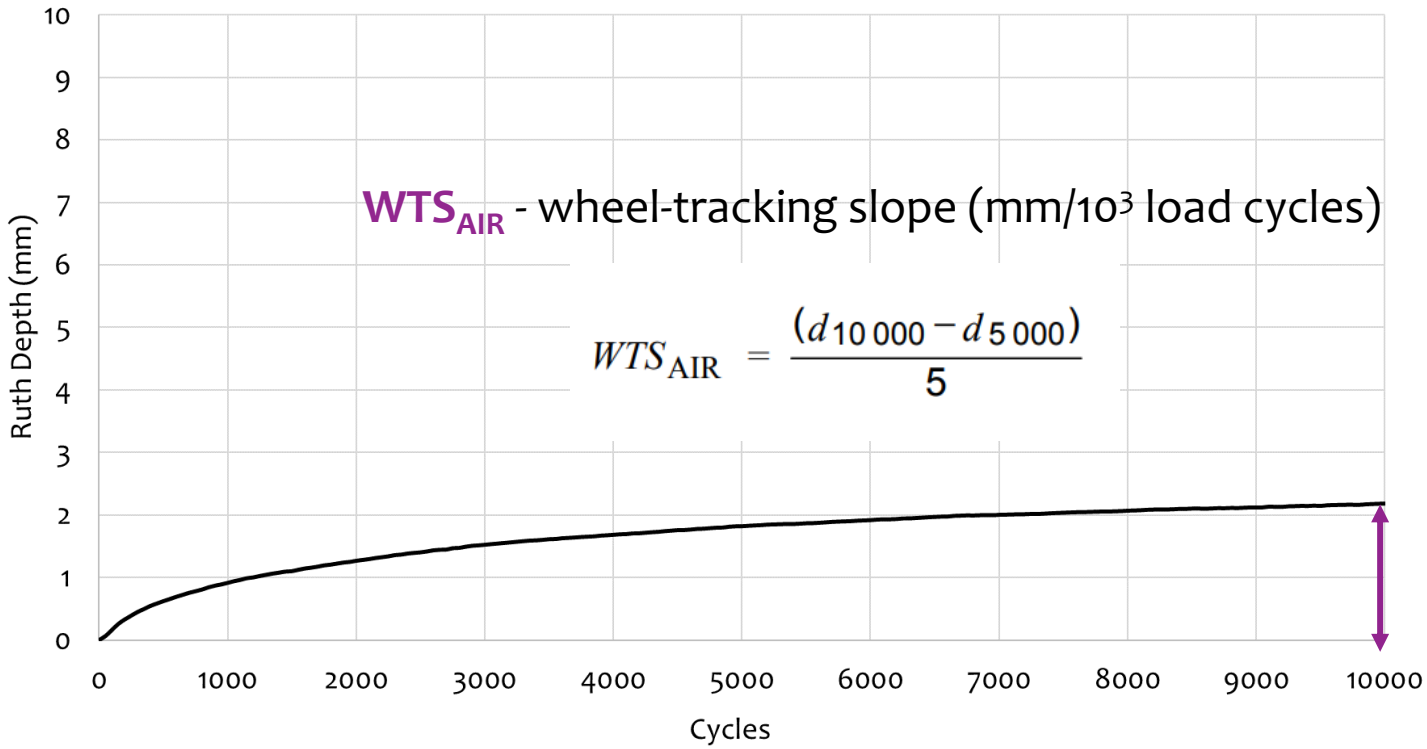
Permanent Deformation

EN 12697-22 - Bituminous mixtures - Test methods for hot mix asphalt

Part 22: Wheel tracking



WTS_{AIR} - wheel-tracking slope (mm/10^3 load cycles)

$$WTS_{AIR} = \frac{(d_{10\,000} - d_{5\,000})}{5}$$

RD_{AIR} rut depth (mm)

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Permanent Deformation

- HMA
  - WCO & 80% RAP
  - WCO & 60% RAP
  - BHO & 60% RAP (tests are running this week!)

- WMA
  - WCO & 80% RAP
  - BHO & 80% RAP

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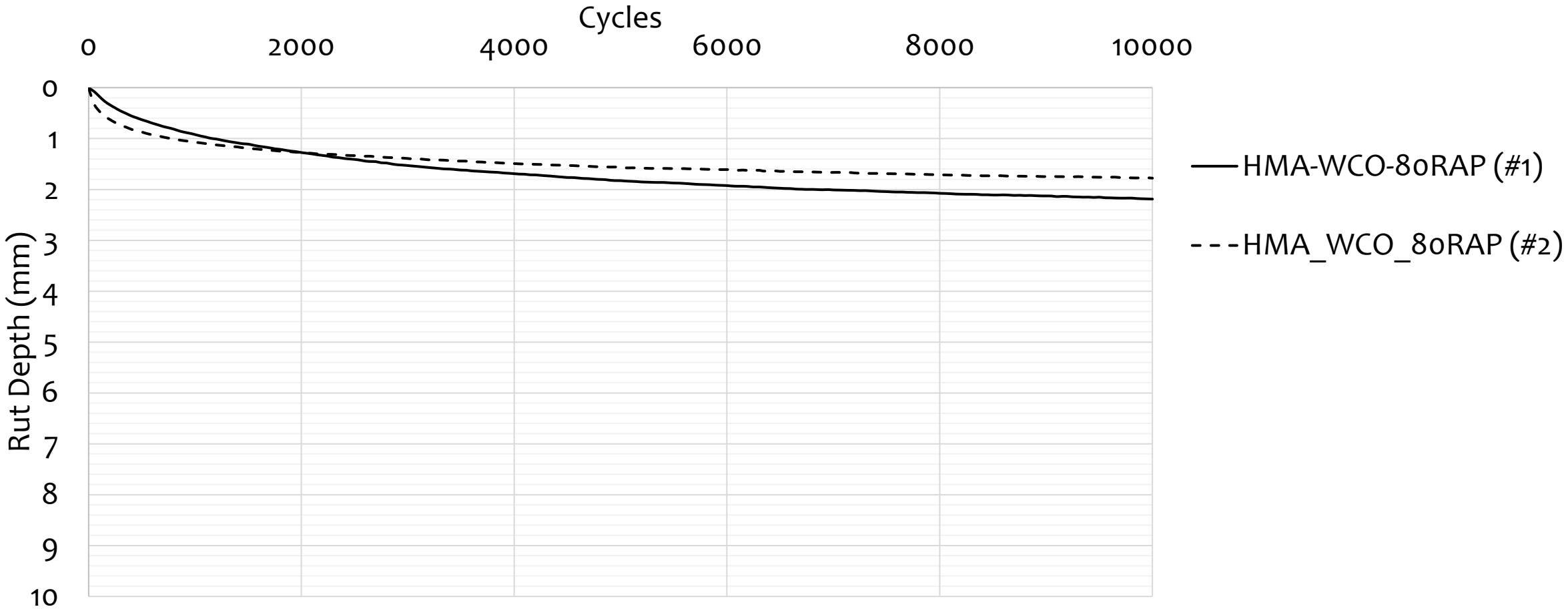
Permanent Deformation



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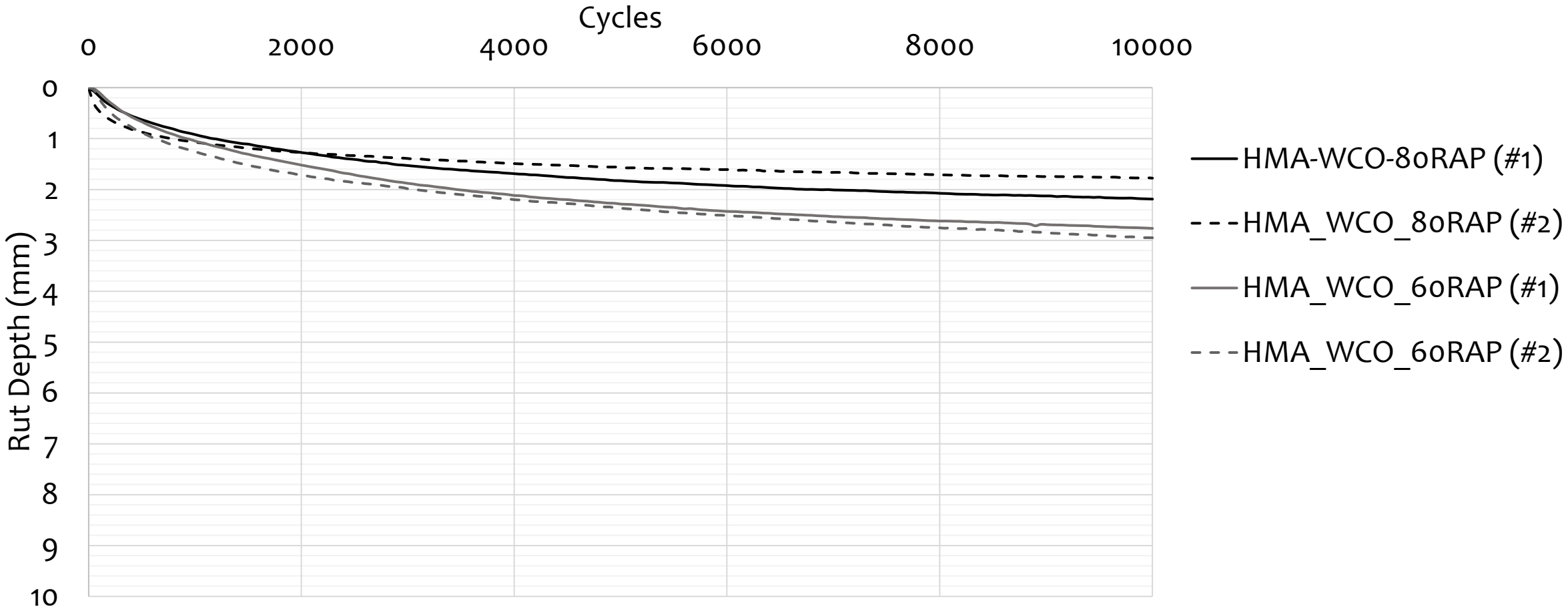

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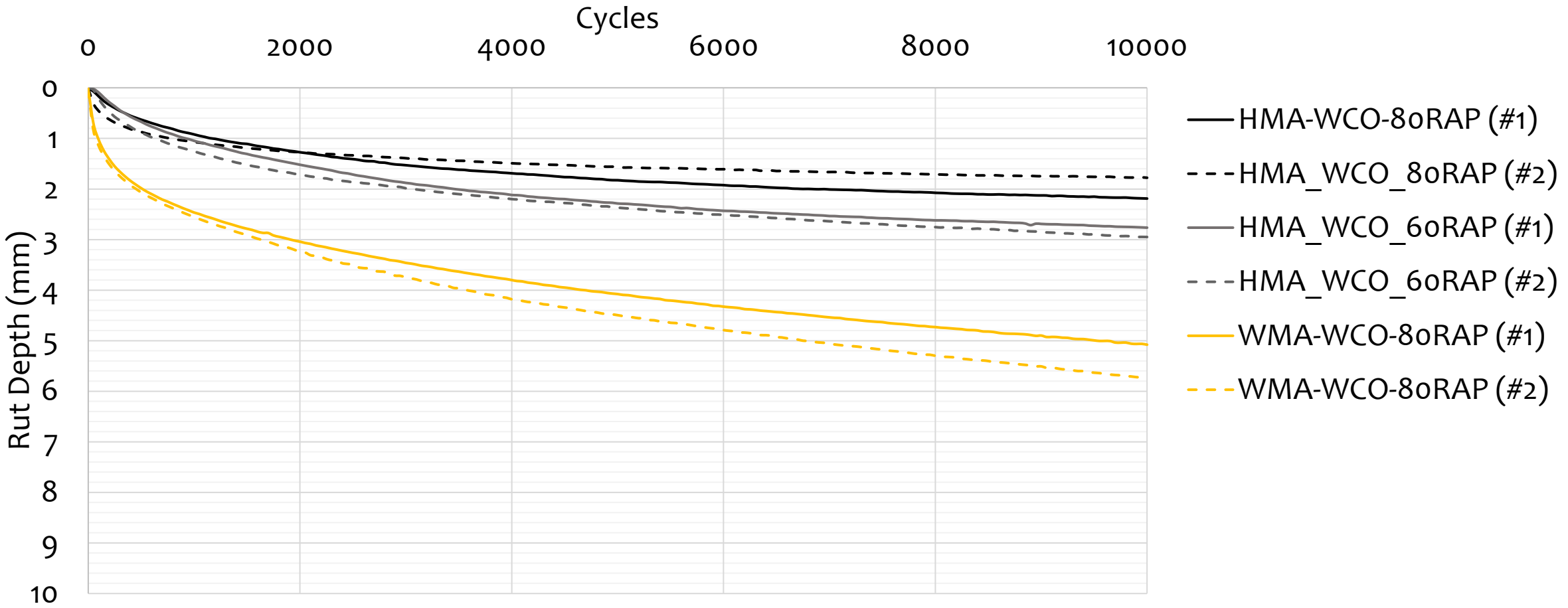
Permanent Deformation



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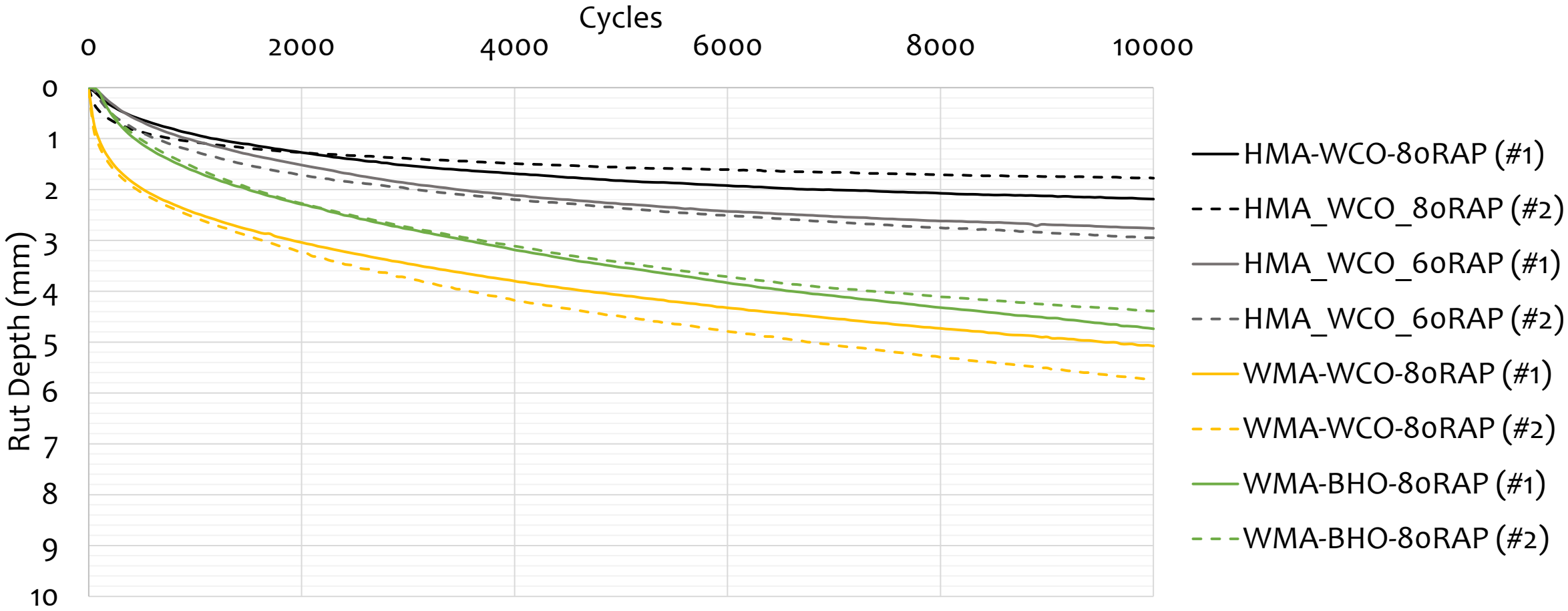
Permanent Deformation



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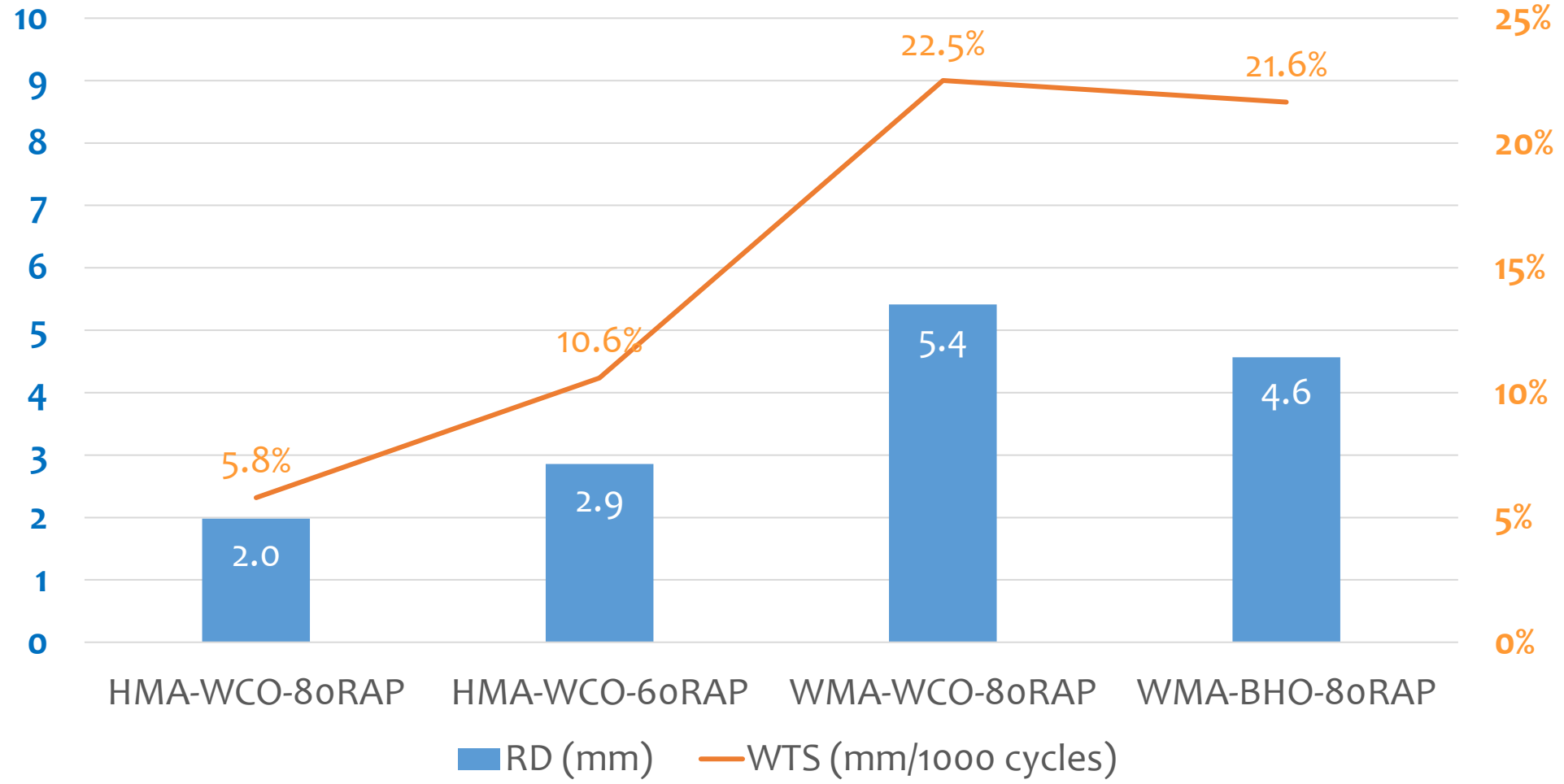
Permanent Deformation



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SKID RESISTANCE
(Pendulum test value, PTV)
EN 13036-4

Mixture	PTV
HMA-WCO-60RAP	74
HMA-BHO-60RAP	72
WMA-WCO-80RAP	72
WMA-BHO-80RAP	73

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TEXTURE
(Volumetric patch technique)
EN 13036-1

Mixture	MTD
HMA-WCO-60RAP	0.69
HMA-BHO-60RAP	0.59
WMA-WCO-80RAP	0.61
WMA-BHO-80RAP	0.49

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Next…

- Workability (gyratory compactor
- Stiffness
- Fatigue resistance
- Pavement trial sections
- Life-cycle assessment

Sustainable Asphalt Rejuvenation using Waste Oils

Grazie!

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